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RESEARCH MEMORANDUM

EFFECT OF AIRPLANE CONFIGURATION ON STATIC STABILITY AT SUBSONIC AND TRANSONIC SPEEDS

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SUMMARY

Some recent wind-tunnel results are discussed relative to several static-stability problems which are currently of interest to the designer of fighter aircraft. Data are presented in both the subsonic and transonic speed ranges and for angles of attack to 25° in many cases.

The results indicate that rather large amounts of taper might provide the best opportunity of obtaining swept wings having high aspect ratios without encountering violent pitch-up and of eliminating the more moderate pitching-moment nonlinearities of moderate-aspect-ratio wings. With regard to the problem of maintaining directional stability throughout the angle-of-attack range, it has been shown that a large number of factors are involved and that, in general, configurations having long expanding fuselage noses, rectangular fuselages, or high wings should be avoided and that care must be exercised in the selection of the longitudinal location of T-tails. Since large variations of pitching moment with sideslip can occur, it may be necessary to consider this effect in the selection of a configuration.

INTRODUCTION

The high-speed capabilities of modern fighter aircraft have been obtained, to a large extent, through changes in geometric and mass characteristics which for many of these aircraft have produced serious stability problems. The purpose of this paper is to discuss recent wind-tunnel results related to some of these problems in the subsonic and transonic speed range. From the numerous problems, those selected for discussion herein are pitch-up and other pitching-moment nonlinearities, the variation of the directional stability parameter with angle of attack, and the effect of sideslip on the pitching moment. The data presented are referred to the body system of axes.

SYMBOLS

C_L	lift coefficient
$C_{L_{MAX}}$	maximum lift coefficient
n	nose length
C_m	pitching-moment coefficient
C_{n_β}	rate of change of yawing-moment coefficient with sideslip
$C_{n_{\beta,t}}$	tail contribution to C_{n_β}
α	angle of attack, deg
β	angle of sideslip, deg
$\Lambda_{c/4}$	sweep angle of wing quarter-chord line, deg
A	wing aspect ratio
c	local chord
λ	wing taper ratio, $\frac{\text{Tip chord}}{\text{Root chord}}$
M	Mach number

DISCUSSION

Longitudinal Stability

Pitch-up.- Considerable research has been conducted in the past with regard to the pitch-up problem (see refs. 1 to 6, for example) and the findings have, to some extent at least, been incorporated in the configurations of modern fighter aircraft. This is illustrated in figure 1 where the combination of wing aspect ratio and quarter-chord sweep angle is plotted for the current fighter configurations. Also presented is the Shortal-Maggin wing pitch-up boundary (derived from wings having moderate taper) with pitch-up occurring above the boundary (see ref. 1) and it will be noted that the wings of current fighters do not exceed this boundary to any great extent in the pitch-up direction. The vertical location of the horizontal tail of these current configurations is indicated by the type of symbol used, with the open symbols representing a high tail, the filled symbols, a low tail, and the half-filled, a tailless configuration. Low tails lie in a region where the rate of change of downwash with angle of attack is decreasing with angle of attack while high tails lie in a region where the opposite trend usually prevails. The 10° line (relative to the chord line) emanating from the trailing edge of the wing mean aerodynamic chord has been found (refs. 7 and 8) to separate these two regions. It will be noted that, in general, the aircraft whose wings lie above the pitch-up boundary have utilized this downwash characteristic of low tails to counteract the wing pitch-up. It should be pointed out that those configurations that are above the boundary but which utilize high tails have experienced pitch-up problems.

Inasmuch as it is desirable, from a drag-due-to-lift standpoint, to utilize wings having high aspect ratios, a transonic wind-tunnel investigation aimed toward developing a 45° sweptback wing with an aspect ratio of 4 (which is somewhat higher than the current fighter configurations, see fig. 1) having satisfactory pitching-moment characteristics has recently been conducted and some of the results are presented in figure 2 for a Mach number of 0.94. On the left side of this figure the pitching-moment coefficient is plotted as a function of lift coefficient for four wing-body combinations varying only in wing taper ratio. For a taper ratio of 0.6 the curve is very nonlinear and indicates an extremely rapid pitch-up. It has been shown in the past that the pitch-up condition for a wing similar to this one can be improved over a large portion of the speed range by means of wing fixes. These fixes, however, require careful tailoring and are usually ineffective at Mach numbers of the order illustrated here possibly because of shock-induced separation over the aft portion of the wing (ref. 6). It is therefore of considerable interest to note that as the wing becomes more tapered the abrupt pitch-up tendency gradually decreases. Instead of an abrupt pitch-up the pointed wing has a gradual decrease in stability starting at a relatively low lift coefficient. This characteristic of highly tapered wings has also been noted at low speeds (ref. 2) and is due, in part at least, to the fact that while tip stall occurs earlier, a smaller portion of the total load is involved and the moment arms are less than on the wings having large tip chords. In addition it should be pointed out that, as the sweepback of the trailing edge is reduced, less area probably lies behind the shocks. (See sketches on fig. 2.) In view of the rather noticeable improvement associated with the pointed wing, a tail-on investigation has been conducted and the results are presented on the right side of figure 2. In an attempt to counteract the gradual decrease in stability the tail was placed slightly (approximately 5 percent of the wing semispan) below the wing chord plane. With the tail on, the wing with a taper ratio of 0.6 still shows a rather severe pitch-up tendency. All of the more tapered wings provided considerable improvement with regard to pitch-up, but it will be noted that nonlinearities still exist at moderate lift coefficients. It should be pointed out, however, that a tail considerably lower than that used is feasible and with a lower tail the pointed wing might, in view of its superior tail-off characteristics, eliminate these nonlinearities.

Nonlinearities at moderate lifts.- Although fairly linear pitching-moment characteristics can quite often be obtained for complete configurations having nonlinear wing-body combinations, there are some undesirable effects of these tail-off nonlinearities. These nonlinearities, for example, can result in violent pitch-downs for swept wings at negative angles of attack, nonlinear stick travel in maneuvers, and, in some cases, the tail loads required for trim can reduce the tail loads available for maneuvers. It is therefore desirable to have wing-body configurations characterized by linear pitching moments. Figure 3 briefly summarizes the results of a systematic wind-tunnel study to develop a linear wing-body combination which in addition to the previously mentioned advantages might not be limited with regard to a satisfactory tail location. The left part of the figure illustrates the approach used in the investigation. For this particular case the basic wing was a 3-percent-thick 45° delta wing, shown on the left side of figure 3, which has a reduction in stability at moderate lift coefficients due to stalling of the highly loaded tip. Rather than attempting to eliminate the reduction in stability at moderate lifts, various amounts of the stalled tips were clipped in an attempt to extend the reduced stability to the low lift range and thereby to obtain a linear curve. The results of clipping the wing to an aspect ratio of 3 is shown by the dashed curve and it will be observed that the pitching moment is linear up to lift coefficients of the order of 0.7 followed by an increase in stability. With this approach, an extensive investigation was conducted (ref. 9) in which the wing sweep angle was varied and various amounts of tip were clipped. What appeared, from a study of these results, to be a very satisfactory plan form is shown on the right side of figure 3. The wing has an unswept 80-percent-chord line, an aspect ratio of 3.5, and a taper ratio of 0.07. In order to determine the characteristics of a complete model employing this wing, a fuselage and tail in several positions were added. The low tail resulted in a gradual increase in stability while the T-tail resulted in a gradual decrease in stability with pitch-up not occurring until the tail enters the wake of the stalled wing. A bitail configuration was also tested and it is interesting to note that the opposite trends of the T- and low tails can be combined to provide an intermediate curve. It should be pointed out that the center-of-gravity position has been adjusted to facilitate a comparison of the curve shapes and that the tail contribution, of course, is dependent upon tail position and area.

Directional Stability

The configuration trends associated with high-performance aircraft have created deficiencies in static directional stability that have been recognized for some time. Recent flight experiences (see ref. 10, for example) in which violent coupled motions were encountered during rolling maneuvers have placed even greater emphasis on the static directional stability problem, and the fact that modern aircraft encounter large angles of attack has made the variation of directional stability with angle of attack extremely important.

Wing-fuselage contribution.- Figure 4 illustrates the variation of directional stability with angle of attack for various wing-body configurations (refs. 11 to 13 and unpublished data) at a Mach number of 0.80. On the left part of the figure the variation for wings having relatively little sweepback is presented and on the right, that for wings having relatively high sweep angles. It will be noted that the unswept wing provides a desirable reduction in the wing-fuselage instability with increasing angle of attack. However, when either moderate or high sweep angles are employed (in the conventional manner) an undesirable increase in the instability occurs. It appears, however, that if sweep is incorporated by means of an M-type composite plan form, desirable characteristics similar to those of the unswept wing can be obtained. Inasmuch as little, if any, leading suction is developed on these thin wings at high angles of attack, it is felt that these variations in directional stability (relative to body axes) are associated with wing-body interference, possibly wing induced sidewash on the fuselage afterbody.

Effect of fuselage shape on tail contribution.- The general trend of increasing wing-fuselage instability with angle of attack indicated in figure 4 points up the importance of minimizing or eliminating any decrease in the tail contribution with angle of attack in order to avoid static instability. With regard to the tail contribution it has been shown in reference 14 that fuselage nose length (the expanding portion of the nose) has an important effect on the location of the fuselage vortices and the resulting flow field in which the vertical tail must operate. In order to illustrate the effect of these flow fields, figure 5 presents the effect of nose length on the tail contribution to directional stability. (With the medium nose the configuration is identical to that of ref. 11.) Here the directional stability contributed by the tail has been normalized by dividing by the value at zero angle of attack and is presented as a function of angle of attack at a Mach number of 0.80 for three nose lengths. On the left side of figure 5 the wing-off results are presented and it will be noted that an increase in the nose length is accompanied by a loss in the tail contribution to directional stability with approximately a 30-percent loss occurring for the long nose at an angle of attack of 20°. From the flow-field studies presented in reference 14 it appears that this effect of nose length is associated mainly with the upward displacement of the fuselage vortices which leaves a larger portion of the tail in the unfavorable sidewash field below the adjacent vortex. On the right side of figure 5, the wing-on results are presented and it will be observed that the addition of the wing had an unfavorable effect. Low-speed studies (ref. 15) indicate that this may be due mainly to the unfavorable wing-alone effect on the tail contribution which occurs for sweptback wings.

The fuselages of modern aircraft, however, quite often depart considerably from a circular cross section and, as was shown in reference 14, departures from a circle can cause large changes in the flow angularity at the tail. The effect that this angularity can have on the tail contribution to directional stability is shown in figure 6 for four different fuselage cross sections. The data were obtained from reference 15 and it should be pointed out that the fuselages are not identical to those of reference 14. All four fuselages had the same longitudinal distribution of cross-sectional area and, of course, the same volume. As in figure 5, the tail contribution normalized by the value at zero angle of attack is plotted against angle of attack. On the left side of the figure the wing-off results are presented. The tail contribution in the presence of the circular fuselage is relatively independent of angle of attack; however, for the two rectangles and the square there is a large loss with increasing angle of attack. For the tall rectangle the departure from the results obtained for the circle begins at about 5° and reaches zero directional stability at about 17°. Above about 20° the stability is restored rather rapidly apparently because of the fact that as the angle of attack becomes large relative to the sideslip angle $\left(C_{n_\beta}\right.$ was obtained over a range of sideslip angle of $\left.\pm 5^{\circ}\right)$ the fuselage vortices tend to become symmetrically disposed relative to the tail and therefore to counteract each other. As the height to width ratio is reduced, the initial instability occurs at higher angles of attack. The wing-on results, presented on the right side of figure 6, indicate that, although the effect of fuselage cross section is somewhat reduced, the characteristics of the square and rectangular fuselages are still undesirable.

Effect of wing height on tail contribution.- Another parameter which was shown in reference 14 to have a large effect on the flow field in the vicinity of the tail is that of wing height. The effect of wing height (obtained from ref. 16 and an extension of the investigation of ref. 15) on the tail contribution to directional stability at low speeds, is presented in figure 7. As in the previous figures, the C_{n_β} contributed by the tail normalized by the value at zero angle of attack is presented as a function of angle of attack. Presented on the left are the results for the configuration having a circular fuselage and on the right, the results for the configuration having a square fuselage. The results for the circular fuselage indicate the usual large loss in tail contribution associated with a high wing. However for the square fuselage little effect of wing height is indicated and rather large losses with angle of attack occur for all three wing heights. By comparing these data with the wing-off results shown on the left side of figure 6, it will be seen that a favorable wing-fuselage interference occurs with the square fuselage, especially when the low wing position is used. This is in contrast to the results for the circular fuselage, which indicate the usual unfavorable interference.

In connection with the favorable wing-fuselage interference associated with the low wing and the square fuselage, figure 8 presents some interesting results of an investigation conducted at high subsonic speeds (ref. 17). Three different fuselage cross sections were investigated in conjunction with a low wing. The results are presented for a Mach number of 0.80 and show that the relationship between the circular and square fuselages is similar to that obtained at low speeds with somewhat similar configurations. However, when only the lower half of the fuselage was square the tail contribution was even greater than that obtained with the circular fuselage. It appears that the unfavorable effect of the square fuselage alone has been eliminated by sufficiently rounding the top corners, while the favorable wing-body interference has been maintained by the relatively square bottom corners.

Three-body configuration.- In addition to the fuselage-shape effects discussed in the preceding sections, the large fuselage volumes required by current fighter configurations contribute considerably to the magnitude of the flow angularity at the tail. In view of this, it was felt that if the required volume were divided between three bodies, large local flow angularities might be reduced somewhat. A preliminary wind-tunnel investigation to determine what type of static directional and longitudinal stability characteristics might be obtained with three-body configurations has been conducted at low speed and some of the results are presented in figure 9. The configuration consisted of one central and two outboard bodies with conventional tail assemblies attached to the two outboard bodies. On the left, the pitching-moment coefficient is presented as a function of lift coefficient, and fairly acceptable longitudinal characteristics are indicated. The rate of change of directional stability with angle of attack is presented on the right and a gradual reduction is indicated above about 8°. However, even at an angle of attack of about 26°, which corresponds to the maximum lift coefficient, only about 30 percent of the total stability is lost. In connection with directional stability, it should be pointed out that this type of configuration has inertia characteristics which, under certain conditions at least, may tend to reduce the inertia coupling problem encountered by many current fighter configurations.

Effect of horizontal tail on directional stability.- Inasmuch as horizontal-tail position is an important factor in connection with longitudinal stability, its effect on directional stability should be discussed. In general, low horizontal tails provide a slight increase in directional stability over that provided by a vertical tail alone. This increase is relatively independent of angle of attack and Mach number at subsonic speeds. T-tails generally provide a rather large increase at low speeds. However, at high subsonic Mach numbers the effect of a T-tail is dependent to a large extent on angle of attack and fore-and-aft position. This is illustrated in figure 10 where the total directional stability parameter C_{n_β} is presented as a function of angle of attack at a Mach number of 0.90. A comparison of the vertical tail alone and the vertical tail with the T-tail in the forward position indicates a large variation of the horizontal-tail effect with angle of attack. Below an angle of attack of about 3° the horizontal-tail effect is unfavorable and results in directional instability at negative angles of attack greater than about 9°. This, of course, could be important during coupled motions where large negative angles of attack can be encountered. When the horizontal tail was mounted in a rearward position the normal low-speed end-plating effect was restored and the variation with angle of attack somewhat reduced. It should be pointed out, however, that the effect of longitudinal position appears to be a function of plan form. For example, the results of reference 13 indicate that with a rectangular vertical and horizontal tail with coinciding leading edges an unfavorable end-plating effect was obtained at high subsonic speeds. It therefore appears that the extent of the vertical tail span over which the adverse chordwise gradients of the vertical and horizontal tails are additive may be more important than the local juncture effect. It appears, therefore, that if a T-tail is desired, extreme care should be exercised in the selection of the fore-and-aft location.

Pitching moment due to sideslip.- A parameter which has received little attention in the past but which is becoming important in connection with the coupled motions is the variation of pitching moment with sideslip. This variation is dependent on a large number of parameters and only a few will be illustrated here. Reference 18 contains a summary of the effects of the various aircraft components. To illustrate the effect that the overall configuration can have, figure 11 presents the variation of the pitching-moment coefficient with sideslip angle for several configurations at a Mach number of 0.80 and zero angle of attack. For the configuration having a sweptback wing and a low horizontal tail, positive increments of pitching moment are indicated with rather large increments occurring with the wing in the high position. For the moderately sweptback wing configuration having a T-tail, large negative increments are produced with increasing sideslip. The fact that large positive or negative increments can occur, depending upon the configuration, indicates that it may be necessary to consider the pitching moment due to sideslip in the selection of a configuration.

CONCLUDING REMARKS

A study of recent subsonic and transonic data indicates that rather large amounts of taper might provide the best opportunity of obtaining swept wings having high aspect ratios without encountering violent pitch-up and of eliminating the more moderate pitching-moment nonlinearities of moderate-aspect-ratio wings.

With regard to the problem of maintaining directional stability throughout the angle-of-attack range, it has been shown that a large number of factors are involved and that, in general, configurations having long expanding fuselage noses, rectangular fuselages, or high wings should be avoided and that care must be exercised in the selection of the longitudinal location of T-tails.

Since large variations of pitching moment with sideslip can occur, it may be necessary to consider this effect in the selection of a configuration.

Langley Aeronautical Laboratory,
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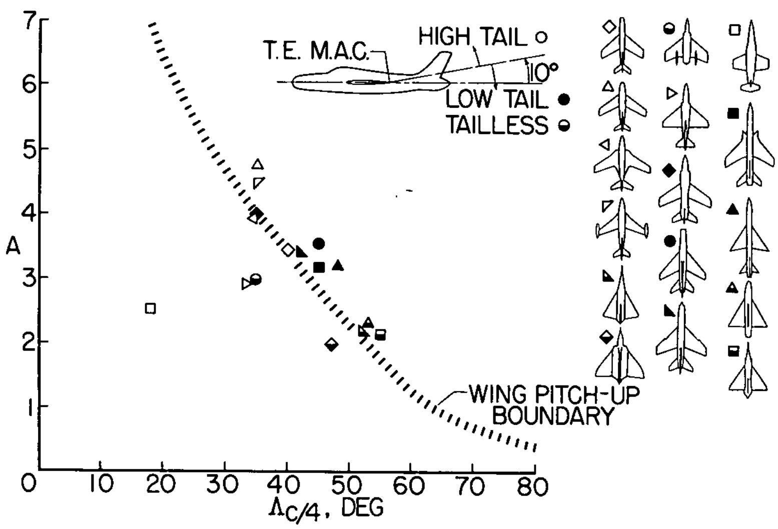

Figure 1

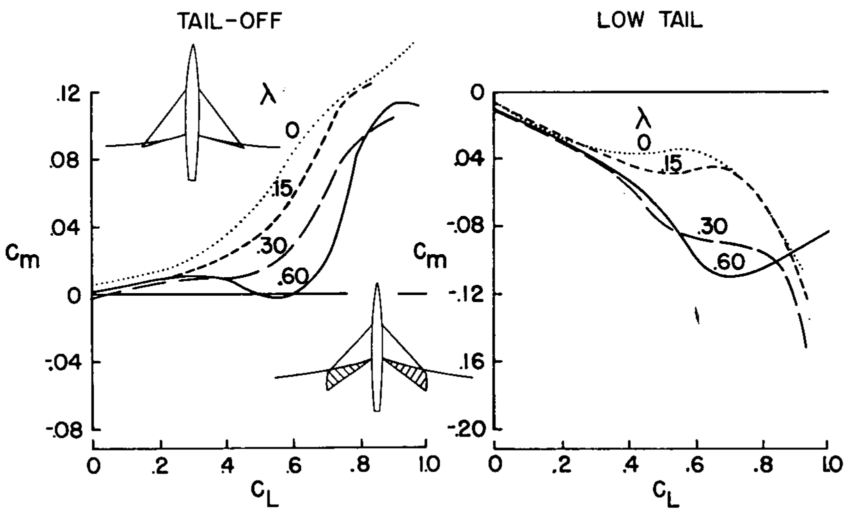

Figure 2

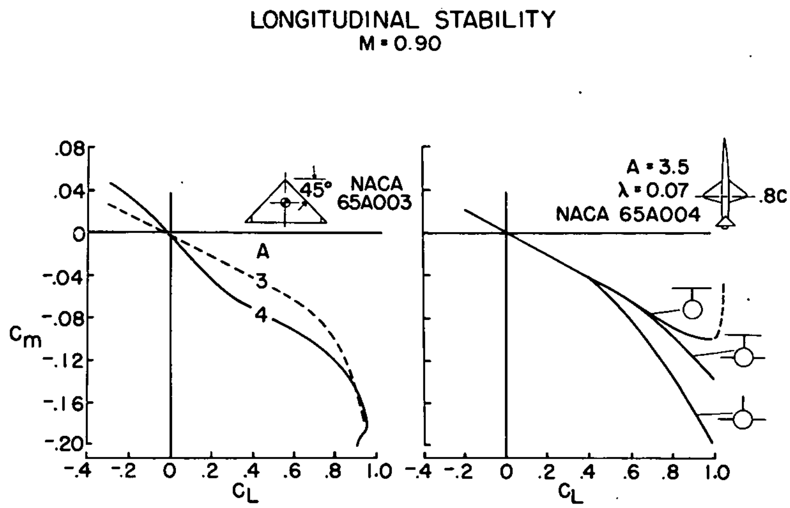

Figure 3

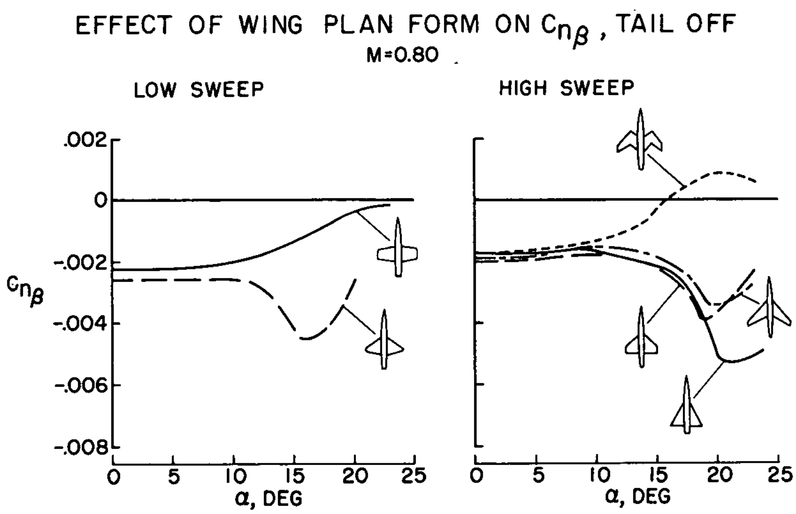

Figure 4

EFFECT OF FUSELAGE NOSE LENGTH ON $C_{n_{\beta,t}}$

M = 0.80

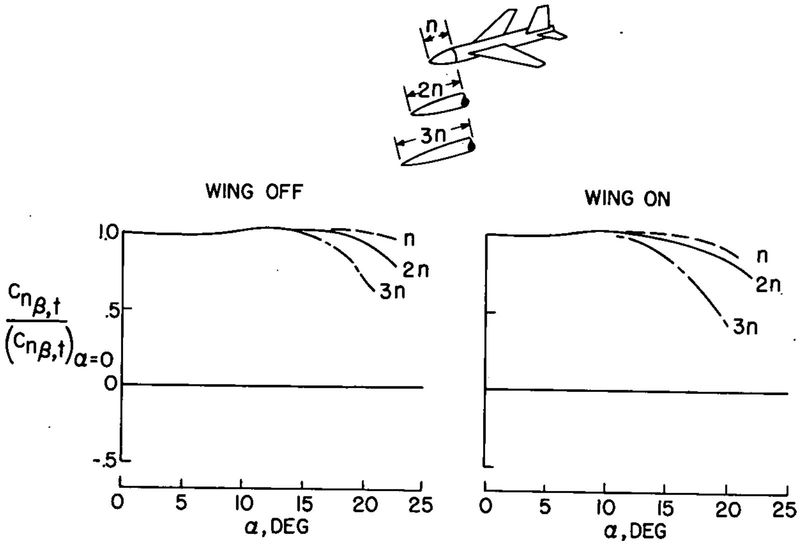

Figure 5

EFFECT OF FUSELAGE CROSS SECTION ON $C_{n_{\beta,t}}$

M = 0.13

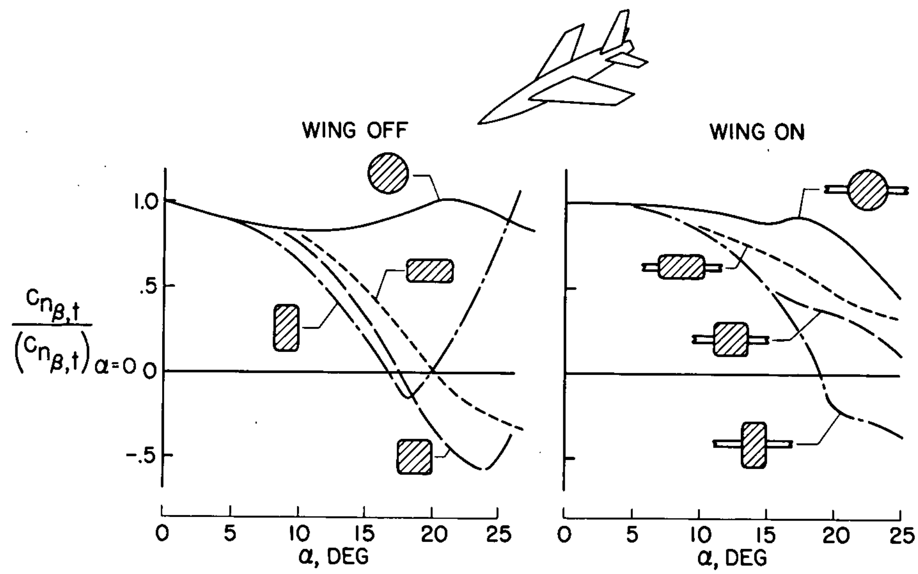

Figure 6

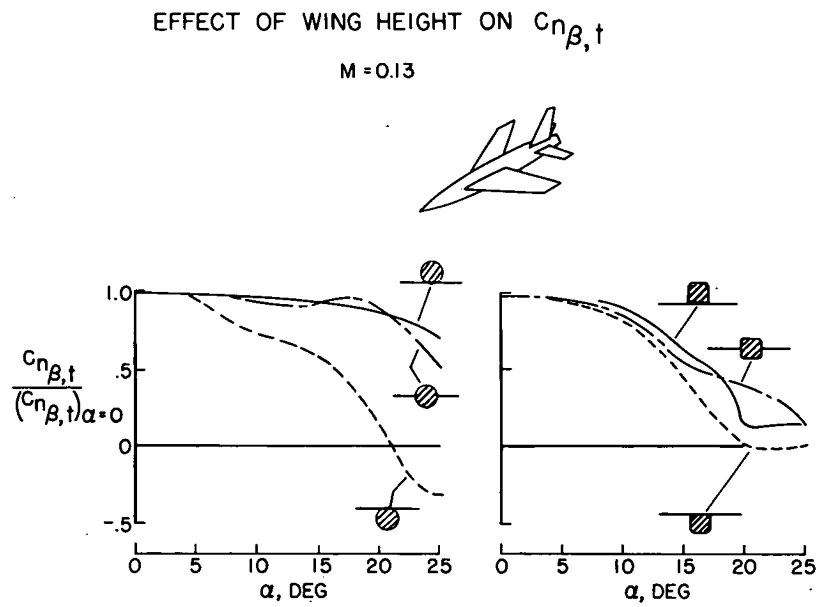

Figure 7

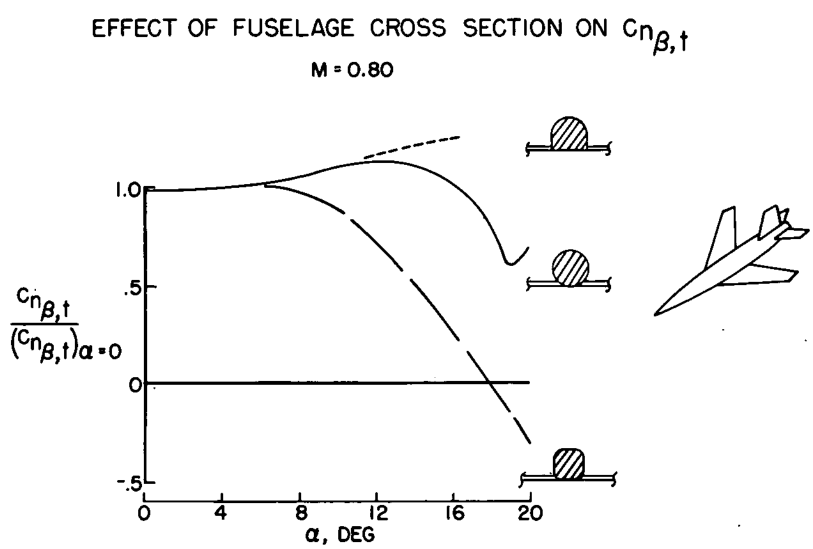

Figure 8

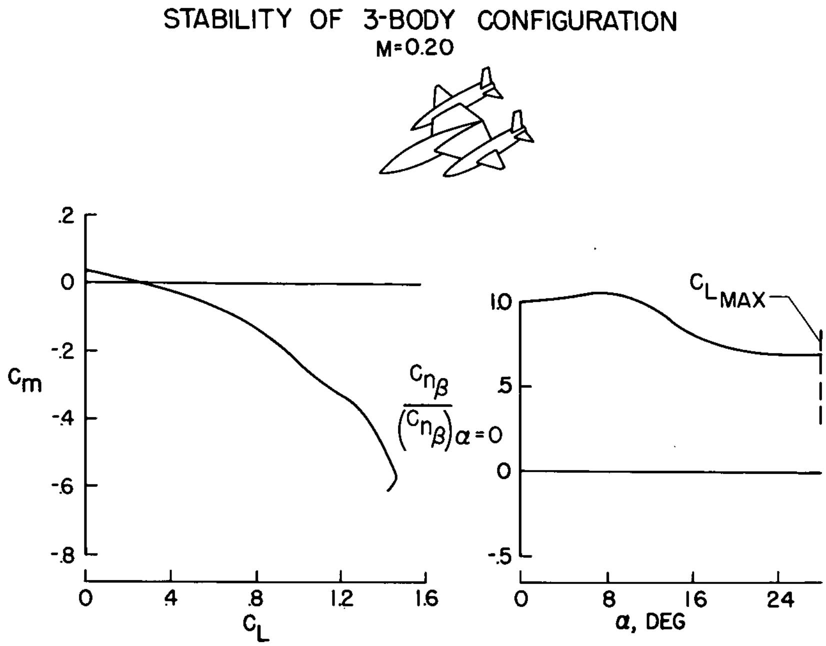

Figure 9

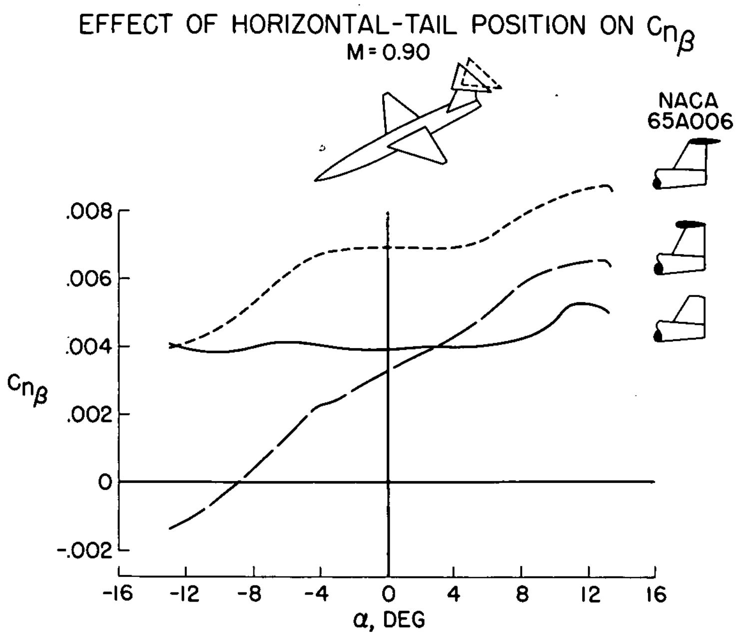

Figure 10

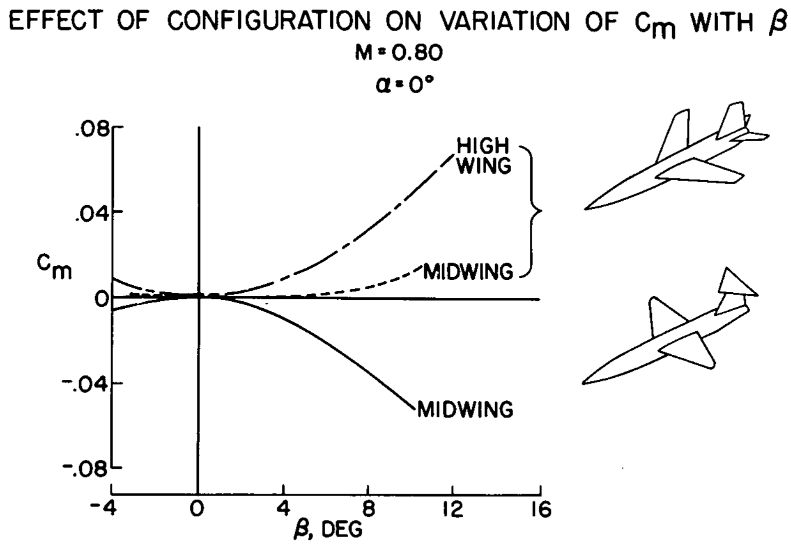
EFFECT OF CONFIGURATION ON VARIATION OF C_m WITH β
M = 0.80
α = 0°
.08
.04
C_m
0
-.04
-.08
-4
0
4
8
12
16
β, DEG
HIGH WING
MIDWING
MIDWING

Figure 11